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54 Method and Apparatus for the Measuring of Object Surfaces by Means of a projected Stripe Pattern

57 Subject matter of the present invention is a method and an apparatus for the surface measurement by means of projected stripe pattern, in which a single grid (3) is projected onto the measurement object (O) through a single projection lens (4), and which is recorded with a single camera (8,9) and single camera (7). For receiving distinct measurants within a large measuring volume (5) a grid (3) is projected with two different imaging scales in a central projection onto the object (O), and for the analysis the beat between the patterns which are projected with different imaging scales is used. In a first embodiment coplanar panels (11,12) are provided for changing of the imaging scale, which can be alternately swivelled into the optical path of the

projection on the side of the measuring object respectively on the side of the grid. In a second embodiment the projection lens (34) features a chromatic enlargement difference. By means of a two-coloured illumination of the grid (33) the grid (33) is projected simultaneously with two different imaging scales onto the measuring object (O), and both patterns are recorded simultaneously with a colour camera (37).

Specification

The present invention relates to a method and an apparatus for the measurement of object surfaces within a measuring volume by means of a stripe pattern being projected onto the object surface according to the preambles of claims 1 respectively 6.

Such measurement methods and corresponding measurement apparatuses are known for example from DE 08 40 07 500 and from EP 03 79 079 A. The measuring apparatus known from EP 03 79 079 comprises within the stripe projector a grid carrier, on which three grids with slightly different periods are arranged. Successively the three stripe patterns are projected telecentrically onto the measuring object, and the distorted stripe patterns on the measuring object are recorded by means of a camera. Through calculative assignment of the residual phase values, which are established through the patterns with different periods, the beat between the projected patterns is generated. The analysis of this beat provides within the measuring volume distinct coordinates of the object surface. Through link-up of this relatively rough coordinate value with the residual phase values of a single projected pattern a coordinate values with a higher accuracy is calculated.

A disadvantage of this familiar apparatus is that because of the telecentrical projection of the stripe patterns only relatively small surface areas can be measured. Furthermore, this measuring device requires several high-precision stripe patterns, whose periods have to be precisely known.

From DE-A-40 07 500 it is further known to project stripe patterns with different periods in a central projection into the measuring volume. By means

of this, even larger surfaces or areas of surfaces may be measured simultaneously. Through the analysis of the beat of both projected patterns with different periods, a detection of the object coordinates is possible with a high precision, too. The analyzation methods being described in this published patent application specification further require the projection of identical patterns through a second projector. As a result this measuring apparatus requires at least two projectors with two projection grids each. From the additional German patent application with the file number P 41 29 796, which corresponds to the European patent application, it is further known to calculate the beat frequency as difference between the measured stripe phases and the reference phases being calculated. Thus it is possible to abandon a third projection system, even with a consistent precision and measuring resolution. However, even in this case at least two grids have to be existent which are projected into the measuring volume.

From EP-PS 0 262 089 a further stripe projection device is known, which requires just a single projector for achieving a similar precision range. In this case two stripe grids are arranged within the projector, which may pivot against each other, and whose Moiré pattern is projected onto the object. By way of rotating the two stripe grids against each other the period of the Moiré pattern may be varied thus being adapted to the particular required precision range.

A stripe projection system that requires just a single grid and a single projector is known for example from US-PS 46 41 972. But in this case just a single pattern is projected onto the object. Thus the measuring of discontinuous object surfaces is possible just within a small precision range.

It is object of the present invention to provide a preferably simple stripe projection system with which even discontinuous object surfaces may clearly be measured within a large measuring volume, which has only a single projector being allocated to the camera, and with which only a single stripe pattern has to be created within the projector. Furthermore, the measurement of large object surfaces should be possible.

According to the invention this task is solved through a method with the characteristics of claim 1 and through an apparatus with the characteristics of claim 6. One and the same stripe pattern with preferably sinusodial brightness control perpendicular to the stripes is projected with at least two different reproduction scales into the measuring volume, and the beat between the patterns being projected with the different reproduction scales is generated.

According to the invention each projection detection system provides just a single stripe projector and a single camera. Within the stripe projector just a single stripe pattern is created. In case the stripe pattern is created by a Ronchi-grid, just a single Ronchi-grid is arranged within the stripe projector. And even in case the stripe pattern is created by an interferometer being integrated into the stripe projector, just a single interferometer is needed.

Preferably the stripe pattern is projected in central projection into the measuring volume. Thus on the one hand it is possible to simultaneously measure large object surfaces and on the other hand to carry out very easily different reproduction scales. The variation of the reproduction scale with a simultaneous use of a single projection lens is possible for example through

the variation of the distance between the grid and the projection lens for example by moving the grid perpendicularly to the grid plane.

However, in a favorable embodiment the grid and the projection lens are arranged with a fixed distance between each other, and merely the positions of the perspective centers of the projection lens on the side of the grid and/or on the side of the measuring volume are varied as defined. In case the positions of the two perspective centers of the projection lens are varied, it is possible to keep constant the image plane of the grids within the measuring volume in both projection situations. Thus the variation of the reproduction scales has no influence on the stripe contrast in the measured spot of the object surface.

In a favorable embodiment of the invention coplanar plates or concentric menisci made of lucent material are provided within the stripe projector, which can be swivelled into the optical path. These coplanar slides or concentric menisci displace the main spot of the complete system in directioin of that side to which the coplanar slides respectively the concentric meniscus is pivoted to. In case the coplanar slides respectively the concentric menisci are pivoted alternately to the side of the test object and the grid, the position of the distinct grid image in both projection settings is identical, if the ratio of their thicknesses corresponds to the square of the reproduction scale.

HAving assemblies with which the optical axes of projector and camera are arranged parallel to each other, the plane slides respectively the menisci should be able to swivel into the optical path in an inclined position with respect to the optical axis of the projector. The rotation causes a

displacement of the perspective centers of the lenses directed to the optical axis as well as perpendicular to the optical axis. This concentrates the effect being achieved by the rotation.

In an alternative embodiment the projection lens is a variable-focus lens, which can be switched into positions with different distanced between the perspective centers, for example by pivoting the coplanar lantern slides by displacing the lens assemblies between two stop positions.

In an especially favorable embodiment the projection lens is provided with a chromatic enlargement defect. Thus it is possible to illuminate the projection grid simultaneously with light of two different colours, and thus to project simultaneously two patterns with a different period into the measuring volume. By means of a colour camera both patterns can be recorded simultaneously but disconnected from each other.

In the following text details of the invention will further be explained by means of embodiments being displayed in the drawings. In detail is shown in:

Fig. 1a a schematic illustration of a first embodiment of the invention with coplanar slides being able to swivel into the optical path of the projection;
Fig. 1b a perspective illustration of the system of the embodiment of fig. 1a comprising the lens and the pivotable slides;
Fig. 1c a chart with the optical paths for examplifying the geometrical assembly;
Fig. 2a a chart of the optical paths with a coplanar plate being pivoted to the side of the measuring object;

Fig. 2b a chart of the optical paths with a coplanar slide being pivoted to the side of the grid;

Fig. 3 a schematic illustration of a second embodiment with a projection lens, which provides a chromatic enlargement defect;

Fig. 4 a schematic illustration of a thid embodiment with parallel aligned projection and camera axes; and

Fig. 5 a chart for examplifying the analysis method being run inside the analysis computer.

The measurement apparatus illustrated in fig. 1a is provided with a light source (1), which illuminates homegenously a grid (3) via a lens (2) with alternating lucent or opaque areas. A projection lens (4) projects the grid (3) in central projection into the measuring volume (5) and onto a measuring object (O) being located within the measuring volume. The stripe pattern being projected onto the measuring object (O) is recorded by a camera (7) which comprises a camera lens (8) and a CCD-sensor (9). The distance between the projection lens (4) and the camera lens is arranged in such a way that the optical axis (4a) of the projection lens (4) and the optical axis (8a) of the camera lens (8) intersect in a point 10) within the measuring volume (5). Within the projector (P) two coplanar lantern slides (11,12) are attached to a drive shaft (13) which runs parallel to the optical axis (4a) of the projection lens. The coplanar slides are each provided with gaps (11a,12a), which are located on opposite sides with respect to the drive shaft (13). In case the drive shaft (13) is rotated by the motor (14) either the coplanar slide (11) between the projection lens (4) and the measuring volume (5) or the coplanar slide (12) between the projection lens (4) and the grid (3) is swivelled into the optical path, i.e. each time a measurement takes place, merely one of the coplanar lantern slides is located within the optical

path. Thus the other coplanar slide is aligned in a way that the projection cone of light exactly passes through the gap (11a,12a) of this coplanar slide. The parallel beam offset being caused by the coplanar slides creates within the central projection a displacement of the projection center in that direction in which the coplanar plate is swivelled. This will be further explained with by means of figs. 2a and 2b.

Each image of the measuring volume, which is recorded by the camera (7), is read out by a computer (18). Afterwards the processor (18) controls via a motor control (19) the drive motor (14), which rotates the drive shaft (13) about 180°. In this case the slide (11) is swivelled out of the optical path of the projection, and the slide (12) is swivelled in between the projection lens (4) and the grid (3). Subsequently the camera (7) records a second image of the measuring volume. The processor (18) analyzes both of the recorded images according to the analyzation method, which will be further described afterwards. The surface coordinates, which are pertinent to the measuring object (O), are graphically displayed on a monitor (19).

The exact assembly of the coplanar slides (11,12) is illustrated in more detail in fig. 1b. Again in this case the projection lens is marked with (4) and its optical axis with (4a). Both coplanar lantern slides are arranged on the shaft (13) which runs parallel to the optical axis (4a). Each of the coplanar slides (11,12) shows a gap (11a,12a), which stretches across a semi circle and whose width (d) is chosen in a way that the particular projection cone is able to pass through the particular gap uncut. For preventing vibrations and agitations the outer edges of the planar slides (11,12) are chosen in a way that their centers of gravity are identical to the center of the shaft (13).

The effect of the coplanar slides (11,12) may simplest be explained with the aid of figs. 2a and 2b. For reasons of simplification it will again be assumed that the projection lens, in case the coplanar slides are not swivelled in, shows just a single perspective center (4b). In fig. 2a the coplanar slide (11) is arranged on the side of the perspective center (4b), which is turned away from the grid (3). Thus the internal perspective center of the complete system is displaced with an amount (d1) from (4b) to (4c). An image (3') of the grid (3) arises within the focal plane (20). As illustrated in fig. 2b, in the contrary case, when the coplanar slide (12) is arranged on the side of the grid within the optical path of the image, the grid-sided perspective center moves about an amount (d2) from (4b) to (4d). But the internal perspective center remains at (4b). Because of the relocation of the perspective centers from (4b) and (4c) to (4d) and (4b), again an enlarged image (3") of the grid (3) arises within the same focal plane (20). By comparing the images (3') and (3") of figs. 2a and 2b it is clearly visible that the image (3") in fig. 2b is larger than the image (3') in fig. 2a. For preventing a displacement of the focal plane (20), to which the grid (3) is sharply reproduced, during the change-over from fig. 2a to fig. 2b, the ratio of the thicknesses (D11,D12) is chosen in such a way that the ratio d2/d1 correspond to the square of the amplification by which the grid (3) is reproduced within the plane (20). It is to be mentioned that for reasons of clarity the thicknesses of the coplanar slides (11,12) in figs. 2a and 2b are illustrated disproportionately in comparison to the object and reproduction distances. Thus in a real measurement assembly these thicknesses are considerably smaller so that the enlargement difference represents just a fraction of the enlargement.

The embodiment of fig. 3 features a lens (34) with a chromatic enlargement defect. The lens (34) shows the dashed plotted principle planes (34b,34c) for

red light and the drawn-through plotted principle planes(34d,34e) for blue light. The measuring object-sided principle planes(34e) for the blue light is placed from the measuring object-sided principle planes for the red light (34c) in the direction of the measuring object (O). Compared to this the displacement of the principle planes (34b,34d) on the side of the grid (33) is exactly in the opposite direction, i.e. the principle plane (34d) for the blue light is closer to the grid (33) than the principle plane (34b) for the red light. The grid (33) will be illuminated homogeneously and simultaneously with a composition of red and blue light by a light source (31), a collector (32) and a colour screen (35), which is arranged between the collector (32) and the grid (33). Because of the different positions of the principle planes (34b,34c) for red light on the one hand and (34e,34d) for blue light on the other hand, the grid (33) coded in terms of colour is projected onto the object (O) with two different reproduction scales. The distances between the principal planes are chosen in a way that for both colours the grid (33) is clearly reproduced within the center (40) of the measuring volume. This results in nearly an identical stripe contrast for both patterns being coded in terms of colour on the measuring object (O). The camera (37) is a colour camera with a convention lens (36) whose optical axis (36a) intersects the optical axis (34a) of the projection lens (34) in the center (40) of the measuring volume. The chip (39) of the camera (37) is provided with a colour mask (39a) so that the pixels of said chip of the camera (39) is, by turns, either sensitive for the red or the blue light. A dispersion prism (38) is arranged in front of the chip (39), by means of which the same point within the measuring volume hits, spectrally splitted, adjacent pixels of the chip (39) of the camera.

Consequently this measurement assembly allows a simultaneous projection, of two patterns being coded in terms of colour of different periodic types onto

the measurement object with just a single grid (33) within the projector, and to record both patterns separately with just a single camera. As the optical axes (34a,36a) of the projection lens (34) respectively the camera lens (36) intersect in one point (40), it is possible to choose a conventional colour camera as camera (37), whose sensor chips (39) show a center point that is almost identical to the optical axis (36) of the projection lens (36).

In the following text the analysis of the stripe pattern which was recorded with the camera may be explained in more detail with reference to figs. 1c and 5, for the case of the convergent assembly, with which the optical axes of the camera lens and the projection lens intersect in one point. In fig. 1c the optical paths of the measurement apparatus are illustrated in a widely schematized way. The camera lens has a measuring-object-sided principal plane (51) and a sensor-sided principal plane (52). The sensor surface of the camera chip is marked as (53). It is arranged with a distance (ap0) behind the camera-sided principal plane (52) of the camera lens. For receiving analysis equations that are as simple as possible, it is advisable to choose the point of interesection of the optical axis (58) of the camera lens with the measuring-object-sided principal plane (51) of the camera lens as point of origin. The projector is arranged sidewisely of the camera. The projector has a projection lens with an optical axis (57) that intersects the optical axis (58) of the camera lens in one point. Furthermore, the measuring object-sided principal plane of the camera lens is marked with (54) and the grid-sided principal plane of the camera lens is marked with (55). The point of intersection between the optical axis (57) of the projector with the measuring-object-sided principal plane (54) shows the coordinates (XP,YP,ZP) with reference to the point of origin. The grid (56) with sinusodial

transmission with the stripe period (G1) is arranged in a distance (ap1) behind the grid-sided principal plane (55) of the projection lens.

The aim is to determine the coordinates (X,Y,Z) of a point (P = X,Y,Z) within the measuring volume from the intensity measurants in a point (X0,Y0) of the camera (53). In fig. 1c the plane of projection is identical to the Y-Z plane so that Y = Y0 = 0.

Initially from the law of projection results that all points that are reproduced in the point (X0,Y0) of the camera sensor (53) define a straight line (60), which is defined by the equation

$$Z \bullet (X0,Y0,ap0)/ap0 \qquad (1)$$

whereas (X0,Y0) are the X- and Y-coordinates of the image point on the camera chip (53).

Furthermore, from the central projection of the grid (56) results that the measuring point (P starts from the grid (56) on a second straight line (61), intersecting the center of projection with the coordinates (XP,YP,ZP) and the initially unknown point (X1,Y1). The straight line (61) is defined by the equation

$$Z1 \bullet M(X1,Y1,ap1)/ap1 + (XP,YP,ZP) \qquad (2)$$

whereas Z1 is the projection of the distance between the measuring-object-sided center of projection (XP,YP,ZP) and the measuring point (P) on the

optical axis (57) of the projection lens, and (M) is the rotary matrix that describes the rotation of the projection axis (57) onto the camera axis (60).

By equating the formulas (1) and (2) it can be derived that the Z-coordinate of the measuring point (P) is defined by the equation

$$Z = \{n11 \bullet XP + n12 \bullet YP + n13 \bullet ZP - (n31 \bullet XP + n32 \bullet YP + n33 \bullet ZP) \bullet X1/ap1\}ap0$$
$$/\{n11 \bullet X0 + n12 \bullet Y0 + n13 \bullet aP0 - (n31 \bullet X0 + n32 \bullet Y0 + n33 \bullet aP0) \bullet X1/ap1\} \qquad (3)$$

whereas n11,n12,n13,n31,n32 and n33 are the coefficients of the inverse M-rotary matrix, which thus describe the rotation of the camera axis (58) onto the projection axis (57). In case Z is known, the X- and Y-coordinates of the point (P) can be calculated from

$$X = X0 \bullet Z/ap0$$
$$X = Y0 \bullet Z/ap0 \qquad (4)$$

In case X1 = P + X0 is additionally set, the equation (3) can be solved for (P) and results with Z0 = Z/ap0

$$P = \{n11(Z0 \bullet X0 - XP) + n12\ (Z0 \bullet Y1 - YP + n13(Z0 \bullet ap0 - ZP)ap1$$
$$\{n31(Z0 \bullet X0 - XP + n32(Z0 \bullet Y0 - YP) + n33(Z0 \bullet ap0 - ZP\} - X0 \qquad (5)$$

In equation (3) all values except for X1 are known from the geometric assembly. As the grid (56) is periodic with the periodicity (G1), X1 can be defined according to the following equation (6):

$$X1 = P + X0 = (N1 + D1)G1 \text{ with } 0 \leq D1 < 1 \text{ and } N1 \text{ being an integer} \qquad (6)$$

In case the stripe order N1 as well as the stripe phase D1 were known, the coordinates could be explicitly calculated with the equations (3) and (4). From the intensity in the point (X0,Y0) of the camera sensor (53) only the stripe phase D1 can be calculated, using with the analysis algorithms that were described in the printed publications which were cited in the beginning.

But in case a second measurement with a different distance ap2 between the grid (56) and the grid-sided principal plane (55) of the projection lens is carried out, for example by swivelling in a coplanar slide between the grid (56) and the projection lens, the phase of the same point (X0,Y0) of the camera sensor (53) is measured in a different point of the grid (56) with the X-coordinate

$$X2 = P2 + X0 = (N2 + D2)\, G1 \text{ with } P2 = P \bullet ap2/ap1 \qquad (7)$$

whereas the stripe phase D2 is determined with the aid of a second measurement.

In case the equations (6) and (7) are solved for N1 and N2 and both equations are subtracted, this results in

$$P = (N12 + D1 - D2)G1/(1 - ap2/ap1) \qquad (8)$$

In this case the beat order (N12 = N1 - N2) has a constant and known value within the measuring volume. The grid parameter (G1), the grid distances

(ap1,ap2) are known as well, and the stripe phase (D1,D2) can clearly be determined from the measured intensities, using the known phase analysis algorithms.

Afterwards the analysis can be executed by means of the flow chart being illustrated in fig. 5, in the following way:

The images of the measuring object, which were recorded by the camera (53), will first of all be digitized, and in a first functional unit (64) the stripe phases of the recorded camera images will be calculated. For example the calculation of the stripe phases in the functional unit (64) can be done with the analysis algorithms known from DE-A 40 14 019. With this method the stripe phase of each pixel of the camera will be calculated in each single camera image. The phase maps which were generated with the phase analysis will be deposited in image memories (65a,65b). Thereby is saved within the first image memory (65a) the phase map, i.e. the stripe phase (D1) for each pixel (X0,Y0) of the camera image, which was recorded with the frist grid distance (ap1) and within the second image memory (65b) the corresponding stripe phases of the camera image is saved, which were recorded with the second grid distance (ap2). By means of creation of the difference between the stripe phases (D1,D2) for each pixel of the camera a coarse value of the variable (P) is calculated in a first calculation step (66), following equation (8), and in a second calculation step (67), which follows equation (3), a coarse Z-value is calculated. In a further calculation step (68) the phase order (N1) is determined using the coarse Z-value and the phase value (D1) following equation (6), whereas the value which was calculated before, is rounded to the next integer. By repeated application of equation (6) in a further calculation step (69) a more precise value for the variable (P)

is calculated from the before determined phase order (N1) and from the stripe phase (D1). By inserting this more precise value for the variable (P) in equation (3) a more precise Z-value is generated in a further calculation step (70). In a caklculation step (71) the X- and Y-coordinates are determined by means of equation (4).

In case the reproduction scale with which the grid (56) is projected onto the object is varied by the swivelling in of a lantern slide to the side of the measuring object, different measuring object-sided projection centers (XP,YP,ZP) derive for both projection situations. This results in different equations (3) for each projection situation and an own equation (5) for the highest values of (P1) and (P2) in both projection situations. By comparing these two equations for the variables (P1,P2), equations can be derived, which are analogous to the equations (7) and (8) and which describe how the variables (P1,P2) are related to each other for both projection situations. Again the analysis takes place according to the flow chart being illustrated in fig. 5, whereas solely different equations for the calculation of the coarse values of the variables (P and Z) from the difference of the phase values (D1 and D2), thus the beat of the patterns being projected with different reproduction scales and which are analogous with the equations (7) and (8) are calculated in the calculation steps (66,67).

In the embodiment of fig. 4 the optical axes (44a) of the projection lens (44) and the optical axis (48) of the camera lens (48) are aligned approximately parallel to each other. With this embodiment it is advantageous to arrange the slides (49,50) in an inclined position with respect to the optical axis (44a) of the projection lens so that the surface normal (49a) of the planar slide (49) includes an angle α with the optical axis (44a) of the projection lens, which is

different from zero. It is because of the inclined arrangement of the coplanar lantern slide (49) that the object-sided projection center is not only displaced in Z-direction, but as well perpendicular to the stripe pattern in X-direction in the second projection situation, during which the planar slide (49) is swivelled into the optical path of the projection on the side of the object. In the second projection situation the projection occurs with a virtual optical axis (44b), which has a different distance from the camera axis (48a). Thus the effect caused by the coplanar lantern slide (49) is amplified so that the coplnar slide (49) may be chosen thinner.

It is to mention that the calculation of the phase maps from the camera images not necessarily have to be done by analysis in the local domain, for example by means of the method being described in DE-A 40 14 019. In fact it is possible, too, to use phase analysis algorithms, which work in the time domain for which thus a multitude of patterns is recorded with the camera, between which a projection grid is displaced within the grid plane in each case. Such analysis algorithms are described for example in EP-A 03 79 079, which was cited in the beginning. In case the determination of the phase values is done in the time domain, even with the method according to the invention and with the devices according to the invention the grid has to be displaced each time within the grid plane. This eventuality is indicated by an arrow (Pf) in fig. 1a.

Claims

1. Method for measuring of object surfaces within a measuring volume by means of a stripe pattern being projected onto the object surface, with a camera for recording the stripe pattern and an analyzation pocessor being downstream behind the camera, for the calculation of the object surface from the stripe pattern being recorded, **characterized in that** the same stripe pattern being generated within the projector is projected with at least two different reproduction scales onto the object surface and the beat of the patterns, which were projected with different reproduction scales is used for the analysis.

2. Method according to claim 1, **charaterized in that** the stripe pattern is projected in each case in central projection into the measuring volume.

3. Method according to claim 1 or 2, **charaterized in that** the stripe pattern is projected in each case through the same projection lens (4,34,44).

4. Method according to one of the claims 1 to 3, **characterized in that** the position of the measuring object-sided projection center (4c) respectively the measuring-object-sided principal plane (34c;34;54) is varied for changing the reproduction scales.

5. Method according to one of the claims 1 to 3, **characterized in that** a single grid (3;33;56) is projected and the distance between the grid (3;33;56) and the grid-sided principal point (4d) respectively the grid-sided principal plane (34b;34d;55) of the projection lens (4;34) is varied.

6. Apparatus for measuring of object surfaces within a measuring volume with

- a stripe projector with a projection lens for the projection of stripe patterns into the measuring volume,
- a camera for recording the stripe pattern being distorted on the object surface,
- an analysis processor being downstream behind the camera, for calculating the object surface from the stripe patterns being recorded, whereas with the use of the beat of two projected patterns of different periods within a large measuring volume, distinct measurants for the object surface are determinable,

characterized in that means (11,12;49,50;34) are provided for changing the reproduction scales with which the stripe pattern is reproduced in the measuring volume.

7. Apparatus according to claim 6, **characterized in that** within the stripe projector a single grid (3;33;56) with a periodic striped transmission trait is arranged, and that the means for changing the reproduction scale are one or several coplanar slides (11,12;49,50) or concentrical menisci, which can be swivelled into the optical path of the projection.

8. Apparatus according to claim 7, **characterized in that** the coplanar slides (49,50) or the concentrical menisci are engageable into the optical path of the projection with an angle α.

9. Apparatus according to one of the claims 7 or 8, **characterized in that** a first coplanar slide (11;49) can be swivelled into the optical path of the projection on the side of the measuring object and a second coplanar plate respectively a concentrical meniscus (12;50) can be swivelled into the optical path of the projection on the side of the grid, and that the ratio of the

thicknesses of both coplanar slides respectively concentrical menisci is proportional to the square of the repdoduction scale, by which the grid (3) is reproduced in the measuring volume (5).

10. Apparatus according to claim 9, **characterized in that** the coplanar slides (11,12;49,50) are engageable alternately into the optical path of the projection on the side of the object respectively on the side of the grid.

11. Apparatus according to claim 6, **characterized in that** within the stripe projector a single grid with a periodic stripe transmission trait is arranged and that for changing the reproduction scale the distance between the grid (33) and the grid-sided principal plane (34b,34d) of the projection lens (34) is changeable.

12. Apparatus according to claim 11, **characterized in that** the projection lens (34) features a chromatic enlargement difference, means (31,32,35) are provided for the illumination of the grid (33) with two different colours and a camera (37) is provided for the separate recording of the patterns, which were projected with different colours.

13. Apparatus according to one of the claims 6 to 12, **characterized in that** the projection lens (4;34) and the camera lens (8;36) are arranged with an angle between each other so that the optical axis (4a;34a) of the projection lens (4;34) and the optical axis (8a;36a) of the camera lens (8;36) intersect in one point (10;40) of the measuring volume.

Concerning this five pages with drawings